ANN Based PID Controlled Brushless DC drive System

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***Abstract*—Brushless (BLDC) DC motors find many industrial applications such as process control, robotics, automation, aerospace etc. Wider usage of this system has demanded an optimum position control for high efficiency, accuracy and reliability. Hence for the effective position control, estimation of dynamic load parameters i.e. moment of inertia and friction coefficient is necessary. This paper incorporates the estimation of mechanical parameters such as moment of inertia and friction coefficient of BLDC motor and load at various load settings by using simple procedure. To achieve the optimum position control, PID controller is employed and tuned using PARR method. ANN training is used for obtaining the mechanical and PID controller parameters at different load settings. Closed loop position control system of the BLDC drive system is created using SIMULINK. Simulation results of this system are obtained at different load settings. It is evident from the results that the position control system responds to the desired position with minimum rise time, settling time and peak overshoot.**

***Index Terms*— BLDC, control, neural, position**

I. Introduction

Estimation of parameters of any physical system plays a vital role to select the parameters of controllers in control applications. This is essential to fulfill the desired performance indices. A lot of research has been carried out in the computation of parameters. Inertia and Friction of motor were estimated but that of load were not considered [1]-[3]. The importance of estimation of load parameters was stressed in [4] but strategies for the estimation were not discussed. If controller is tuned based on motor parameters [5]-[8] only, then such a system may not yield desired response. Precision and accuracy are of utmost importance in tuning controller parameters to achieve the desired response without the loss of stability. The controller tuning was done taking into account mechanical parameters of motor as well as load in which inertia and friction are either already known or specified [9]-[13]. However, variation of load parameters under dynamic load variation was not accounted. This paper presents a simple method to determine the inertia and friction of BLDC motor and load under dynamic load variations. Using the method, inertia and friction of BLDC motor and load are estimated at five different load settings using a SIMULINK model. PID controller is tuned by PARR method to optimize the performance of the position control system. ANNs are used to obtain these parameters and PID controller parameters at any load setting. Using the transfer function model, step response of position control system is obtained at different load settings.

II. Estimation Of Inertia And Friction

A. Method

Inertia J and friction B of BLDC motor and load can be determined from "(1)" and "(2)" respectively.

$$J = B\tau \cdot \tag{1}$$

$$B = \frac{K_T i_a}{\omega} . \tag{2}$$

where K_T is torque constant, T_e is electromagnetic torque, i_a is armature current per phase, ω is angular speed, τ is mechanical time constant of motor and load. T_e, i_a and ω are found out when BLDC motor runs at steady speed for any load current. Time taken for the motor speed to drop from the steady speed to 36.8% of the steady speed gives τ for that load current.

B. Estimation of J and B at Different Load Curents

Transfer function of Brushless DC position control system [14] is given by

$$\frac{\theta(s)}{E_a(s)} = \frac{K_T}{s[(R_a + sL_a)(Js + B) + K_b K_T]} . \tag{3}$$

The BLDC motor is rated 24V, 8 poles, 4000 rpm, 0.125 Nm, 0.036 Nm/A, 48e-7 kg-m^2, 1e-5 Nm-sec/rad, 1.08ohm per phase and 1.8mH per phase. Transfer function of the position control system using the BLDC motor with these ratings is given by

$$\frac{\theta(s)}{E_a(s)} = \frac{0.036}{8.64*10^{-9}s^3 + 5.184*10^{-6}s^2 + 1.296*10^{-3}s}$$

SIMULINK model of BLDC motor fed by a six step inverter used for the estimation of parameters is shown in Fig. 1. 24V DC supply is given to the motor through a switch controlled by a timer. The gates of the respective switch in the inverter are controlled based on hall sensor signals. The outputs of the inverter are applied to the PMSM (Permanent magnet synchronous machine) block's stator windings. Ratings of BLDC motor are selected in block parameters of PMSM. Load torque (T_L) is given as step input in Nm. Simulation is run. The electromagnetic torque (T_e) and the speed responses of

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the motor can be viewed. As an illustration, rotor speed and electromagnetic torque responses at no load are obtained and shown in Fig. 2 and Fig. 3 respectively. Using “(1)” and “(2)”, friction and inertia are computed from Fig. 2 and Fig. 3 as 8.72e-6 Nm-sec/rad and 4.03e-6 Kg-m^2 respectively. These values are in good agreement with the parameters used in Block parameters. Similarly, J and B are determined from no load to rated load in steps of 20% using this method, tabulated in Table I and used as targets to compute J and B at any load setting. For this, neural network with architecture shown in Fig. 4 is used. Levenberg-Marquardt training is used.

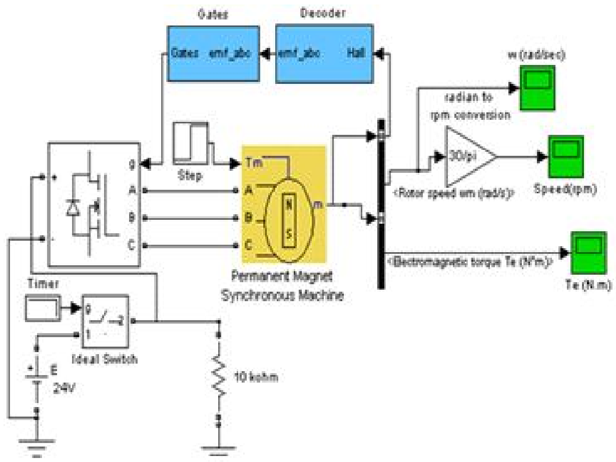

Figure 1. BLDC motor fed by a six step inverter

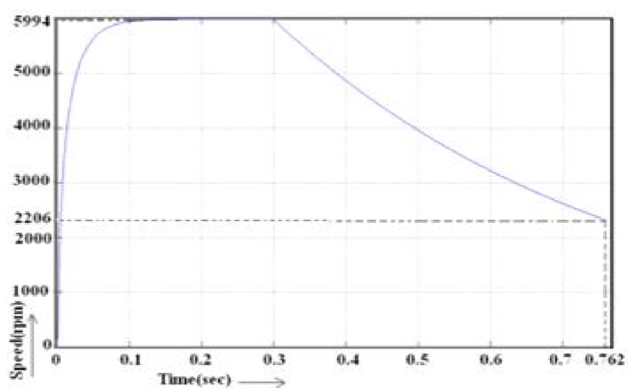

Figure 2. Speed response at no load

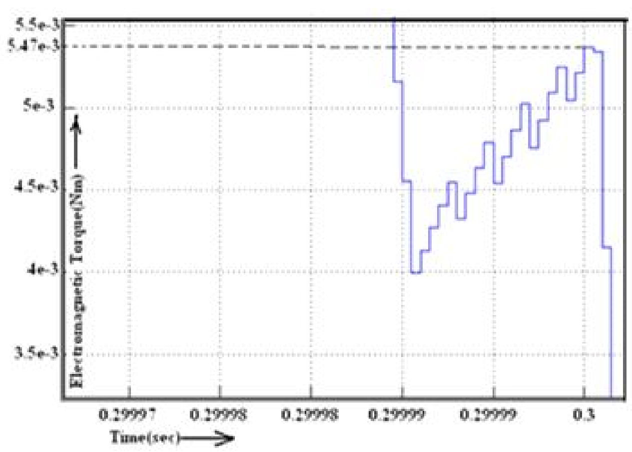

Figure 3. Electromagnetic torque response at no load

TABLE I. ESTIMATION OF J & B AT DIFFERENT LOAD CURRENTS

T_L (Nm)	ω (rad/sec)	T_e (Nm)	τ (sec)	B (Nm-sec/rad)	J (kg-m^2)
0	627.5	5.47e-03	0.462	8.72e-06	4.03e-06
0.025	517	0.0278	0.055	5.38e-05	2.96e-06
0.05	433.5	0.0629	0.025	1.45e-04	3.63e-06
0.075	366.3	0.08	0.0146	2.18e-04	3.18e-06
0.1	311.2	0.0974	0.0096	3.13e-04	3.00e-06
T_L (Nm)	ω (rad/sec)	T_e (Nm)	τ (sec)	B (Nm-sec/rad)	J (kg-m^2)
0.125	265	0.1218	0.0068	4.54e-04	3.13e-06

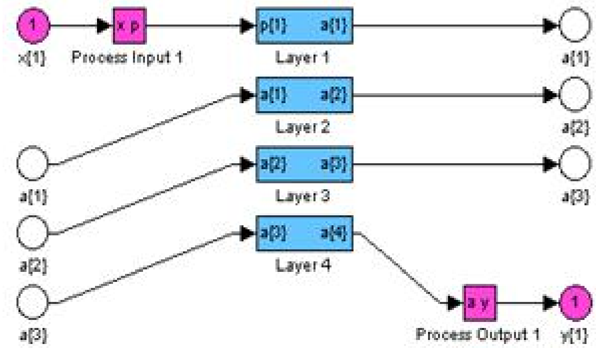

Figure 4. Neural network Architecture

III. PID CONTROLLER TUNING

PID controller parameters viz. K_p, T_d and T_i are found out at different load torques using PARR tuning rule [15], shown in Table II and used as targets to compute them at any load using another neural network shown in Fig. 4.

TABLE II. COMPUTATION OF PID CONTROLLER PARAMETERS

T_L (Nm)	J (Kg-m^2)	B(Nm-sec/rad)	K_p	T_d(sec)	T_i(sec)
0	4.03e-06	8.72e-06	11.2	0.0029	0.0146
0.025	2.96e-06	5.38e-05	11.65	0.0025	0.0125
0.05	3.63e-06	1.45e-04	12.95	0.0027	0.0133
0.075	3.18e-06	2.18e-04	14.25	0.0024	0.0121
0.1	3.00e-06	3.13e-04	16	0.0023	0.0114
0.125	3.13e-06	4.54e-04	18.55	0.0022	0.0111

IV. ANN TRAINED POSITION CONTROL SYSTEM

SIMULINK model of ANN trained position control system is shown in Fig. 5. There are two closed loops in the position control system with one loop representing the system without any controller while another the system with PID controller. ANNs used for estimation of J, B, PID controller parameters are used in the model. Load torque is selected. Step response of the position control system is simulated. As an illustration, load torque is selected as 0.09375 Nm (75% of rated load) in the load torque block of Fig. 5. Uncontrolled output is shown in Fig. 6. PID controlled output is shown in Fig. 7. Performance

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specifications viz. rise time(t_r), peak overshoot(M_p), settling time(t_s) and steady state error (e_{ss})are measured from the responses Simulation results of uncontrolled and PID controlled responses are obtained at different load torques and shown in Table III. From Table III, it is evident that PID controlled system yields position output with smaller rise time and settling time compared to uncontrolled system at any load.

TABLE III. SIMULATION RESULTS OF ANN TRAINED POSITION CONTROL SYSTEM

T_L (Nm)	Uncontrolled system			PID controlled system			
	t_r (msec)	t_s (msec)	e_{ss}	t_r (msec)	M_p (%)	t_s (msec)	e_{ss}
0	72.2	131.6	0	3.73	27.9	30.9	0
0.025	74	135.1	0	3.745	26.9	31.2	0
0.05	81.1	148	0	3.585	24.9	31.2	0
0.075	85.87	156.5	0	3.435	23.9	31.5	0
0.1	92.89	168	0	3.274	22.8	31.3	0
0.125	102.3	185.4	0	3.062	21.2	30.6	0

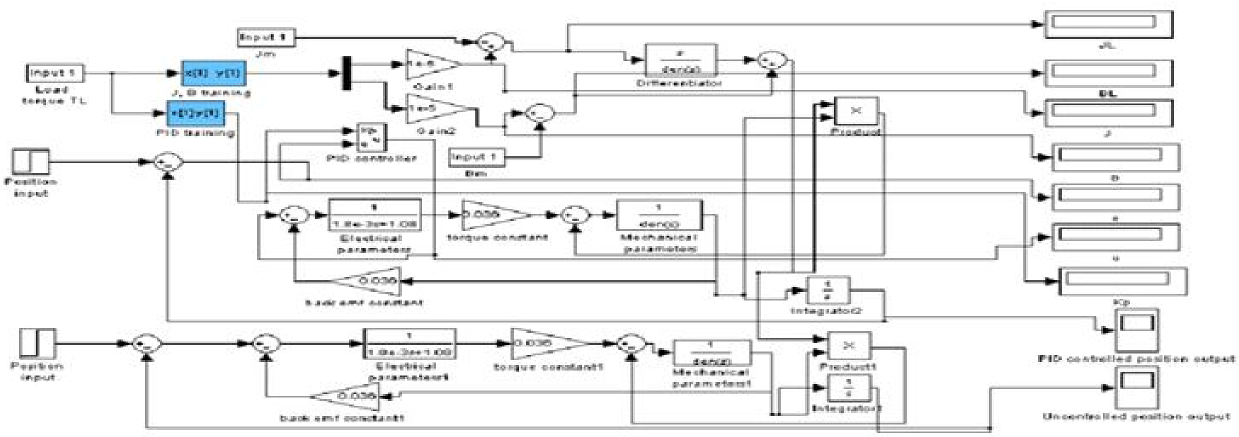

Figure 5. ANN trained Position control system

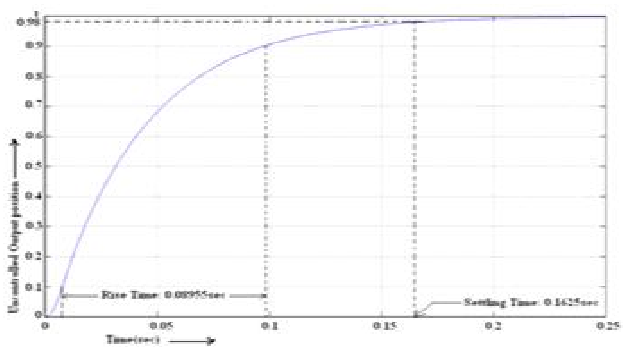

Figure 6. Uncontrolled Output

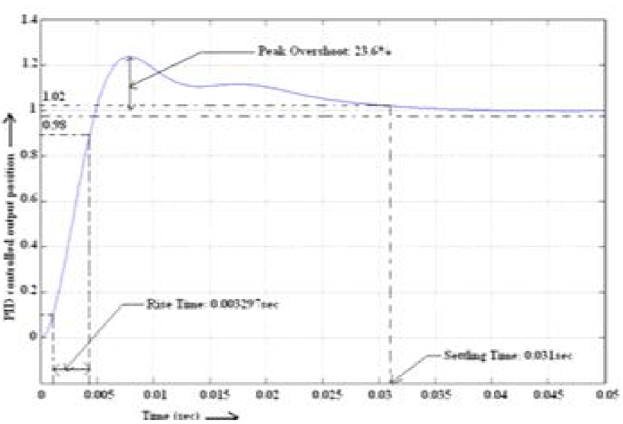

Figure 7. PID controlled Output

CONCLUSIONS

BLDC position control system employing the proposed method of the estimation of inertia, friction and PID controller parameters could yield optimum position control at any load setting. Further, the controlled position is independent of the load. Proposed method can be effectively used for controlling the BLDC drive systems of different ratings. This method can be implemented in real time by employing appropriate torque and speed sensors and advanced digital signal processors. Auto tuning can also be done for the estimation and PID controller tuning in real time.

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